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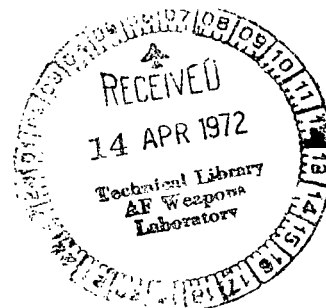
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RESULTS OF INTRA-VEHICULAR MANNED CARGO-TRANSFER STUDIES IN SIMULATED WEIGHTLESSNESS

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16. Abstract A parametric investigation has been conducted in the water immersion simulator at the Langley Research Center to determine the effect of package mass, moment of inertia, and size on the ability of man to transfer cargo in simulated weightlessness. Results from this study indicate that packages with masses of at least 744 kg (51 slugs) and moments of inertia of at least 386 kg-m ² (285 slug-ft ²) can be manually handled and transferred satisfactorily under intravehicular conditions using either one- or two-rail motion aids. Data leading to the conclusions and discussions of test procedures and equipment are presented.					
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SUMMARY

A parametric investigation to determine man's capability to perform intravehicular cargo-transfer tasks in simulated weightlessness has been conducted in the water immersion simulator at the Langley Research Center. Packages with masses up to 744 kg (51 slugs), volumes up to 4 m³ (142 ft³) and moments of inertia about their center of mass of up to 386 kg-m² (285 slug-ft²) were used. All tests were conducted using both one- and two-rail motion aids.

The subjects were able to transfer satisfactorily all the packages tested. Based on subjects' comments, it was concluded that (1) the effects of package mass, size, and moment of inertia are minimal; and therefore, the maximum size package to be transferred will probably be determined by the restraints of the space vehicle; that is, tunnel size, hatch openings, and so forth, rather than by man's capabilities; (2) even though the cargo could be handled with the use of a one-rail motion aid, a two-rail motion aid is preferred; and (3) the use of a two-man team substantially reduces the task effort for large packages.

INTRODUCTION

The transfer of large quantities of a wide variety of cargo will be a requirement in future long-duration manned space missions. It is important to determine in the early planning stages of these missions the limits of astronaut participation in cargo transfer. Several preliminary studies using ground-based simulation have been conducted on various aspects of the problem. For example, one zero-g simulation study (ref. 1) has indicated that man can control and transfer packages with masses up to a limit of 73 kg (5 slugs). In contrast, other studies (refs. 2 and 3) have indicated that man can handle packages up to approximately 146 kg (10 slugs). Such studies have generally been limited in scope, and the results obtained are difficult to correlate because of the differences in simulation and testing techniques used.

In an attempt to examine man's cargo-transfer capabilities in a more comprehensive manner and to contribute information toward the development of a set of guidelines, a series of studies have been conducted at the Langley Research Center. The overall program is designed to investigate man's ability to control and transfer cargo for both intravehicular (IVA) and extravehicular (EVA) activities. The initial phase of the program, discussed herein, was a parametric study to determine the limits of IVA manual cargo-transfer capability. The package parameters (mass, moment of inertia, etc.) were varied so that their criticality, with respect to the overall transfer task, could be determined. Tests were carried out using the water-immersion technique to simulate weightlessness. The results of this study should be useful in the determination of the IVA cargo-transfer tasks which can be accomplished manually and those which require mechanical assistance.

SYMBOLS

Values are given in both SI Units and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

m	mass of the package, kg (slugs)
I	moment of inertia, kg-m^2 (slug-ft ²)
V	volume, m^3 (ft ³)
X,Y,Z	reference axes
$\Delta X, \Delta Y, \Delta Z$	package dimensions, m (ft)
Subscripts:	
c.m.	refers to center of mass
1,2,3	moment-of-inertia axes as defined by sketches in tables I and II

EQUIPMENT

Facilities

All tests were conducted in the water immersion simulator (WIS) at the Langley Research Center (fig. 1). The WIS is 6.1 m (20 ft) deep and 12.2 m (40 ft) in diameter.

The facility has three large windows for observation and photographic purposes and is equipped with three closed-circuit television cameras. These cameras, which can be remotely controlled to track the subject, allowed all tests to be recorded on video tape for data purposes. In addition, for selected tests, motion pictures and still photographs were taken.

Package Construction

All simulated packages were constructed of styrofoam spheres for floatation, 1-inch (nominal size) galvanized pipe for shape, and lead for ballast. A typical package is shown in figure 2. The package shown used lead-filled pipes to obtain the desired mass and moment of inertia. A number of individual packages were constructed and tested. These packages were then used as basic building blocks for larger packages. The mass, moments of inertia about the primary axes and about possible handle locations, and dimensions of the basic packages are presented in table I. Table II gives the same parameters for the various combinations of the basic packages.

The sphere-and-pipe construction was chosen to provide minimum hydrodynamic drag as is discussed in reference 4. This construction also provided a convenient means for attaching lead strips as needed to balance the package to neutral buoyance (fig. 2). The subject was allowed to use any point on any of the pipes on the periphery of the package for handholds.

Motion Aids

The motion aids provided were handrails made from 1-inch, nominal, galvanized pipe spaced 0.46 m (1.5 ft) apart and supported 1.5 m (5 ft) above the floor of the WIS to assure that the subject would not inadvertently contact any other surface. The rails formed a rectangular course with inside dimensions of 3.0 m (10 ft) by 6.1 m (20 ft), part of which can be seen in figure 3.

Subject Equipment

The subjects were dressed in custom-fitted wet suits equipped with a series of small pockets located on the suit at the chest, back, and upper and lower arms and legs (fig. 3) to accommodate strips of sheet lead or styrofoam as needed to make the subjects neutrally buoyant. The subjects wore a standard scuba weight belt and mask. Breathing air was supplied through an umbilical hose to eliminate the effects of the change in buoyancy of a scuba bottle as air is used. By exercising breath control, the subject was able to maintain his neutral state throughout the test.

PROGRAM PLAN

The test series was organized so that each subject started with what was considered a nominal package which could be used as a standard for comparison (package 1, table I). Each subject was instructed to traverse the rectangular course in a headfirst, faceforward manner, keeping the trailing edge of the package forward of his shoulders. During the initial traverse, for each package, a subject was limited to the use of a single pipe rail, and for the second traverse he was allowed to use both rails as desired. No other constraints, such as velocity limitations, specific points of contact on the packages, or procedure for negotiating turns, were imposed on the subjects. The subjects were instructed to pretend that the packages were solid; therefore, they made an effort to look around rather than through the packages.

After each traverse the subjects were asked to evaluate the task and give separate ratings for each of the following factors:

(a) Translational maneuverability – The effort associated with accelerating and decelerating the package in linear motion.

(b) Visibility – The ability to accomplish the tasks in terms of visibility as a function of package size.

(c) Rotational maneuverability – The effort associated with the rotational control of a package about its various axes.

(d) Task effort – The relative amount of effort expended by the subject to complete the transfer tasks.

The evaluations were based on a rating scale (table III) developed to fit the conditions of this study (a modified version of the standard pilot rating scale). Ratings from 1 to 6 were considered acceptable and a rating of 7 or above was considered unacceptable.

After each test period the subjects were questioned to determine the reason why each package was given a particular rating and to ascertain the interrelation of the factors rated. It should be noted, however, that each rating is relative only to the factor being rated. Therefore, the numerical ratings given for one factor cannot be compared directly with those for another factor without taking the subject's comments into consideration.

TEST-SUBJECT QUALIFICATIONS

The results obtained from this study are based primarily on the subject rating data provided by three test subjects. Test subject 1 was a qualified NASA engineering test pilot. Much of his simulation experience has involved testing of vehicles and methods of

locomotion in a reduced-gravity environment. Test subject 2 was an NASA astronaut with Apollo flight experience. Test subject 3 was a practicing USAF Flight Surgeon with approximately 800 hours of flight time.

All the subjects were qualified in scuba diving procedures.

RESULTS AND DISCUSSION

As indicated in the program plan, the basic approach taken was to start with a package of moderate mass, volume, and moment of inertia as represented by package 1 of table I. This package was then used as a standard for comparison. In the remainder of the tests the mass, volume, and moment of inertia were varied in a random fashion for the purpose of determining a subjective limit (7 or higher on the subject rating scale, table III) for at least one of the factors rated. However, the largest combination of packages used (table II) did not provide a rating of 7 or higher. Therefore, a maximum limit on mass, volume, or moment of inertia for man's capability to move cargo in a weightless environment was not defined.

The discussion of the results obtained from this test series attempts to point out general trends and techniques based on the subjects' ratings and comments. Where appropriate, the subjects' ratings are presented in both test-data form (actual ratings) and as normalized averages. The data were normalized by taking the difference between the rating given by a subject for the reference package and 1, which is the best possible rating (table III), then subtracting that difference from each of that subject's ratings. The normalized data for each package were then averaged. The data in this form provide a comparison between the two motion aids used.

One factor which must be considered in any water-immersion study is the effect of hydrodynamic drag. While a complete analysis of package drag is beyond the scope of this report, the drag for the reference package was measured by determining the force required to pull the package through the water at constant velocities. Drag forces were found to correspond to a constant (3.447) times the square of the velocity. Therefore, if the reference package were given an initial velocity of 0.21 m/sec (0.7 ft/sec), it would take approximately 95 seconds to reach a velocity of less than 0.003 m/sec (0.01 ft/sec); during this time it would cover a distance of approximately 1.26 m (4.13 ft). The maximum average velocity used by the subjects during the tests was less than 0.21 m/sec (0.7 ft/sec), as can be seen in figure 4 where the subjects' average velocity is plotted as a function of package mass for both the one- and two-rail cases. Therefore, based on the low velocities used by the subjects and the correspondingly low package drag, the drag effects should not have appreciable effect on the trends noted in the results.

Translational Maneuverability

The data presented for translational-maneuverability ratings are based on each subject's ability to start and stop linear motion. Figure 5 shows subjects' ratings for one and two rails and the normalized averages for one and two rails as a function of package mass.

As indicated by the normalized curves and verified by subjects' comments, the effect of mass on translational maneuverability was relatively insignificant. The subjects commented that they preferred using two rails to one rail; however, the number of rails used did not significantly affect the ratings given. Consequently, it is concluded that package mass, for the range tested, is not a limiting factor in terms of translational maneuverability.

Visibility

The subjects were instructed to pretend that the boxes were solid; consequently, in maneuvering the package they were to look at the relationship between a side and the bottom of the package and the motion aids (rails). The larger boxes required the subject to change his position periodically on the motion aids in order to observe his progress, particularly at the corners. This frequent body positioning caused an increase in the overall workload and resulted in a degrading of the visibility rating as package size increased. This is shown in figure 6 where the subjects' visibility ratings are shown as a function of package volume for all the packages tested.

The normalized-average curves given in figure 6 indicate that the subjects' ratings were not influenced appreciably by the number of rails. Although the subjects stated they preferred the two-rail system, they felt that their method of coping with the visibility problem was basically the same for both cases. Therefore, from the standpoint of visibility, the number of rails used was not significant.

Rotational Maneuverability

The rotational-maneuverability factor is to a large extent a function of package moments of inertia. The following discussion refers only to the moments of inertia about the axis normal to the motion aids (generally the $Y_{c.m.}$ -axis as defined in tables I and II) as a matter of convenience. It should be noted, however, that the subjects' rotational-maneuverability ratings were based on the overall effect of the moments of inertia on package rotational control and not just on the moments of inertia used for plotting and discussion purposes.

The subjects' rotational-maneuverability ratings for one rail and two rails and the normalized averages for one and two rails are shown in figure 7 versus package moment of inertia about its center of mass. The curves can be broken into three fairly distinct areas.

The three areas can be explained as a function of the technique used to control the package. The subjects tended to handle a package with small moments of inertia as if it were an extension of their arm, feeling that no special attention to package control was required. In the range from 20.3 to 67.8 kg-m² (15 to 50 slug-ft²), two items of interest were noted. First, the forces required to control the packages caused a change in technique (the packages became a separate entity), and inputs were applied so that the package tended to rotate about its own center of mass. Secondly, in this range of moment of inertia, when a subject attempted to apply an input, he would move as much as or more than the package unless he was securely and properly anchored. For the package with moments greater than 67.8 kg-m² (50 slug-ft²) the transition in technique and stability required had been completed; consequently, little effect was noted as a result of further increases in moment of inertia.

The normalized-average curves (fig. 7) show clearly that the use of two rails was preferred to one rail and that the subject ratings for packages with moments greater than 67.8 kg-m² (50 slug-ft²) did not increase in proportion to package moment of inertia.

Task Effort

The task-effort factor was used as a means of determining the test subjects' opinion concerning the degree of difficulty of the transfer task considering all factors. Each of the subjects stated that the task effort required was primarily a function of package moment of inertia, with mass and volume relegated to secondary roles. The task-effort ratings were therefore basically equivalent to those given for rotational maneuverability.

The subjects' task-effort ratings for one rail, two rails, and the normalized averages for one and two rails are given in figure 8 as a function of the moment of inertia about the package center of mass. The curves show the same trends as the rotational-maneuverability curves presented in figure 7.

The task effort for performing cargo transfer did not increase in direct proportion to increase in moment of inertia, mass, and/or volume as might be expected. This can be attributed to the fact that the subjects were able to alter their technique for both package and body control as a function of package moment of inertia (see section entitled "Rotational Maneuverability") and motion-aid utilization. Each subject was encouraged to develop his own techniques with respect to the use of the motion aids. The techniques developed can generally be placed in three basic categories.

The technique used for packages with moments of inertia about their center of mass of less than about 20.3 kg-m² (15 slug-ft²) (fig. 8), resulted in the subjects' assuming an essentially prone position on the motion aids. The utilization of the legs and feet was a matter of convenience and comfort, rather than necessity. The feet, when used,

provided a drag force by squeezing the rails, allowing the subjects to control their translational velocity better.

For packages with moments of inertia in the range from about 20.3 to 67.8 kg-m² (15 to 50 slug-ft²), two rails were preferred and the techniques used resembled a crawl (fig. 9). Here the subject placed his instep and calf on the outside of the rails and one hand on the rail. He applied forces so that his legs "squeezed" the rails, and by alternating his grip between his legs and hand, he could in effect crawl. When he was required to exert precise control over the package, he could anchor himself securely with his legs and use both hands on the package.

The packages with moments of inertia in the range above 67.8 kg-m² (50 slug-ft²) allowed the subject to use a "walking" technique (fig. 10). In this case the subject squeezed the rails with his insteps and gripped the package with both hands. The moments of inertia of the packages were sufficient to allow the packages to be used, in effect, as an anchor point or third rail. By alternating the forces applied between the rails and the package, the subject could proceed along the rails in an almost upright position. When additional body control was required (at the corners), the subject could easily assume the crawl position.

Each subject was asked, in the case of the large packages, whether he would prefer to break the package into smaller components or whether he would move the package "as is." In all cases the subjects stated that they would move the complete package. The difference in effort required between the smaller packages and the larger packages was not sufficient to warrant the effort required to disassemble the unit into its component parts and the multiple transfers required. This is emphasized by the fact that the largest package tested was rated by each subject as being within the limits of his manual transfer capabilities.

Handholds

The pipe construction of the packages, as seen in figure 2, provided a variety of possible handholds, and the subjects were allowed to use any of the pipes needed. (They were not, however, permitted to reach into the interior of the package.) For packages with small moments of inertia (less than approximately 20.3 kg-m² (15 slug-ft²)), precise control could be maintained regardless of hand position, and normally only one hand was used. For the range of moment of inertia between 20.3 and 67.8 kg-m² (15 and 50 slug-ft²) the subjects began to use a variety of handholds dependent upon the control input required and the package moment of inertia. These inputs, when a two-rail mobility aid was used, could have been accomplished even if no handhold had been present. That is, the use of both hands allowed the subject to squeeze the sides of the package to obtain an adequate grip.

Additional research is desirable to determine optimum handhold placement. However, for packages with large masses and moments of inertia it may be advantageous (especially if standardized cargo containers are to be utilized) to place lightweight railings around the edges of the packages (in the same manner as the mockups used). The railing, properly designed, could be utilized for package transfer, tiedown, and as a bumper or energy absorber in cases of inadvertent impacts with the vehicle interior during transfer operations.

Transfer Velocity

The transfer velocity was not a parameter in these tests. However, several items of interest were noted with respect to the subjects' average speed. Figure 4 shows average speed for subjects 1 and 2 plotted against package mass. (Average speed for subject 3 was not obtained because of equipment malfunction.) Subject 1 set himself the challenge of keeping very tight control of the package at all times including stopping at the corners and turning the packages within the minimum possible volume (simulating a 90° corner in a tunnel). This resulted in relatively low average velocities. Subject 2 maintained positive control of the package but did not slow down for the corners, as he felt that this required additional effort. This approach resulted in higher average rates. All the subjects felt that the speed used was primarily a function of the task rather than any limitation imposed by the underwater environment.

The subjects' general feeling was that a primary factor associated with cargo transfer is, as stated by subject 3, ". . . discipline or, more specifically, patience obtained as a result of training and experience. In a weightless condition, a slow gentle force applied over a longer period of time is necessary, whereas here on earth we apply force more strongly and expect a quicker reaction. Thus, psychologically, work in a weightless state can lead to frustration, and frustration to wasted effort." It can be noted from the curves in figure 4 (subjects' average velocity versus mass) that in general as mass increases, the subjects' average velocity decreases, apparently because of the need for more precise and patient control inputs and slower accelerations. It can also be noted that on the average the subjects' velocity is higher with the use of two rails than with one rail. The subjects commented that this could be attributed to the improved body control obtainable when a two-rail motion aid is used.

Two-Man Team

A brief evaluation of a two-man team effort was undertaken. One subject placed himself in front of the 744-kg (51-slug) package and the other took a position behind the package. They then proceeded around the motion aids. After one circuit they reversed their positions and completed a second circuit of the motion aids. The subjects did not

experience any difficulties, and in fact each stated that he thought the other was "doing all the work."

Subject 1 rated all four factors at 1.5 and subject 2 rated all of them at 1. They both felt that the task was extremely easy and that they could anticipate each other's actions without the need for communication other than hand motions.

The 744-kg (51-slug) package was the largest available, and since without prior briefing and training the effort required to transfer it was minimal, no additional tests were conducted. The subjects commented that using two men reduced their individual effort to approximately one-fourth of that required to handle the package alone.

Transfer of an Incapacitated Person

The ability of a subject to transfer an incapacitated person was briefly investigated by subjects 1 and 2. One subject was instructed to act as an incapacitated person while the other subject transferred him around the motion aids, first using one rail and then two rails. The subjects' roles were then reversed. Both subjects commented that the transfer task was extremely easy and that positive control of the person being transferred could be maintained with a minimum of effort for either one or two rails.

SUMMARY OF RESULTS

Based on the results obtained from the study conducted to define man's capability to perform intravehicular manual cargo transfer, the following observations were made:

1. The largest package tested, with a mass of 744 kg (51 slugs), a moment of inertia about its center of mass of 386 kg-m^2 (285 slug-ft²), and a volume of 4 m^3 (142 ft³), was well within the subjects' cargo-transfer capabilities; therefore, no limits on manual-cargo transfer were established.

2. The subjects commented that the package rotational maneuverability was the prime factor involved in the overall task effort, with visibility and translational maneuverability relegated to secondary roles.

3. The subjects could control and transfer all the packages tested by using only a one-rail motion aid. However, a two-rail motion aid was definitely preferred for packages with moments of inertia about their center of mass greater than approximately 20.3 kg-m^2 (15 slug-ft²).

4. The maximum size (mass, moment of inertia, and volume) package a man can transport in an intravehicular situation will probably be determined by the restraints of the space station, that is, tunnel size, hatch opening, and so forth, rather than by man's

capabilities. However, additional studies using mockups of spacecraft will be needed to verify this point.

5. Two-man operation substantially reduces individual effort required for transferring large packages.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., March 23, 1972.

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TABLE I.- BASIC PACKAGES

(a) SI Units

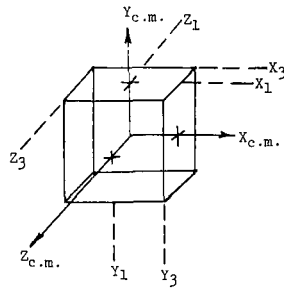
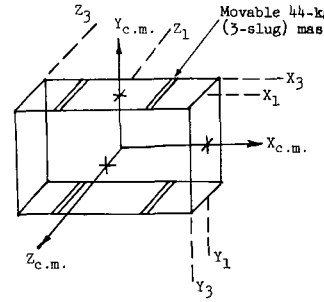
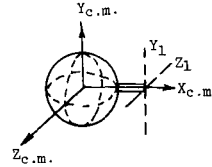
Sketch of package	Package	Approximate dimensions			Approximate volume, V , m^3	Mass, m , kg	Earth weight, N	Moment of inertia, I , $kg\text{-}m^2$, about -								
		ΔX , m	ΔY , m	ΔZ , m				$X_{c.m.}$	X_1	X_3	$Y_{c.m.}$	Y_1 or Y_2	Y_3	$Z_{c.m.}$	Z_1 or Z_2	Z_3
	1	0.61	0.61	0.61	0.23	49	480	7.2	11.3	15.5	7.2	11.3	15.5	7.2	11.3	15.5
	2	.61	.61	.61	.23	91	934	12.8	20.4	28	12.8	20.4	28	12.8	20.4	28
	3	1.1	1.1	1.1	1.2	73	725	19.6	35	51	19.6	35	51	19.6	35	51
	4	1.1	1.1	1.1	1.2	136	1334	50	86	122	50	86	122	50	86	122
	5	1.2	0.76	0.76	0.71	244	2402	41 to 63, 73 to 97	107 to 130	23 to 105	107 to 189	127 to 223	41 to 101	124 to 185	158 to 219	
	6	4.31-cm diameter			0.042	46	449	0.3	-----	-----	0.3	4.7	-----	0.3	4.7	-----

TABLE I- BASIC PACKAGES - Concluded

(b) U.S. Customary Units

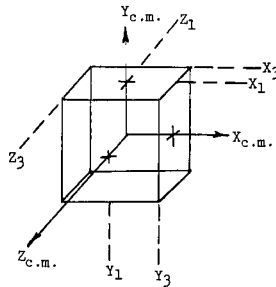
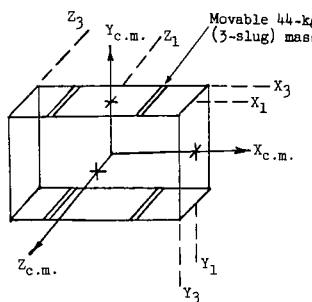
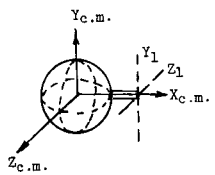
Sketch of package	Package	Approximate dimensions			Approximate volume, V, ft ³	Mass, m slugs	Earth weight, lbf	Moment of inertia, I, slug-ft ² , about -								
		ΔX , ft	ΔY , ft	ΔZ , ft				$X_{c.m.}$	X_1	X_3	$Y_{c.m.}$	Y_1 or Y_2	Y_3	$Z_{c.m.}$	Z_1 or Z_2	Z_3
	1	2	2	2	8	3.35	108	5.3	8.4	11.5	5.3	8.4	11.5	5.3	8.4	11.5
	2	2	2	2	8	6.25	210	9.5	15.1	21	9.5	15.1	21	9.5	15.1	21
	3	3.5	3.5	3.5	42.8	5.0	163	14.5	26	38	14.5	26	38	14.5	26	38
	4	3.5	3.5	3.5	42.8	9.32	300	37	63.6	90.2	37	63.6	90.2	37	63.6	90.2
	5	4	2.5	2.5	25	16.75	540	30 to 47	54 to 72	79 to 96	17 to 78	79 to 140	94 to 165	30 to 75	92 to 137	117 to 162
	6	17-inch diameter			1.49	3.13	101	0.2	-----	-----	0.2	3.5	-----	0.2	3.5	-----

TABLE II.- PACKAGES CONSTRUCTED WITH BASIC PACKAGES AS BUILDING BLOCKS

(a) SI Units

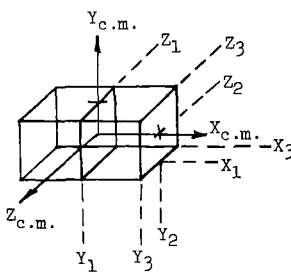
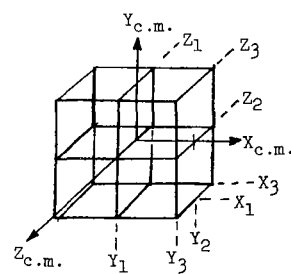
Sketch of package	Basic packages used and position	Approximate dimensions			Approximate volume, V , m^3	Mass, m , kg	Earth weight, N	Moment of inertia, I , $kg\cdot m^2$, about -														
		ΔX , m	ΔY , m	ΔZ , m				$X_{c.m.}$	X_1	X_3	$Y_{c.m.}$	Y_1	Y_2	Y_3	$Z_{c.m.}$	Z_1	Z_2	Z_3				
	<table><tr><td>1</td><td>1</td></tr></table>	1	1	1.2	0.61	0.61	0.45	98	961	14.3	23	32	23	31	57	65	23	31	57	65		
	1	1																				
	<table><tr><td>1</td><td>2</td></tr></table>	1	2	1.2	.61	.61	.45	144	1414	20.2	32	44	31	45	66	77	31	45	66	77		
	1	2																				
<table><tr><td>2</td><td>2</td></tr></table>	2	2	1.2	.61	.61	.45	190	2091	26	41	56	42	57	103	117	42	57	103	117			
2	2																					
<table><tr><td>3</td><td>4</td></tr></table>	3	4	2.1	1.1	1.1	2.43	210	2059	70	122	173	113	174	250	301	113	174	250	301			
3	4																					
	<table><tr><td>1</td><td>1</td></tr><tr><td>2</td><td>2</td></tr></table>	1	1	2	2	1.2	1.2	0.61	0.91	287	2829	65	158	182	62	89	131	154	86	113	155	178
	1	1																				
	2	2																				
<table><tr><td>3</td><td>1</td></tr><tr><td></td><td>1</td></tr></table>	3	1		1	1.4	1.2	.76	1.16	343	3363	46	173	204	85	146	298	331	93	231	306	435	
3	1																					
	1																					
<table><tr><td>3</td><td>2</td></tr><tr><td></td><td>2</td></tr></table>	3	2		2	1.4	1.2	.76	1.16	435	4270	65	225	266	111	176	305	346	124	315	351	498	
3	2																					
	2																					

TABLE II. - PACKAGES CONSTRUCTED WITH BASIC PACKAGES AS BUILDING BLOCKS - Continued

(b) U.S. Customary Units

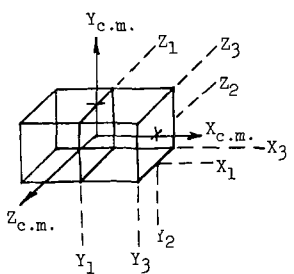
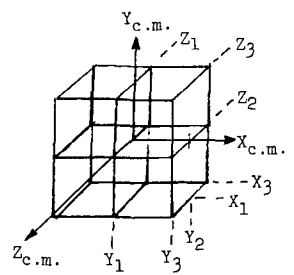
Sketch of package	Basic packages used and position	Approximate dimensions			Approximate volume, V, ft ³	Mass, m, slugs	Earth weight, lbf	Moment of inertia, I, slug-ft ² , about -												
		ΔX, ft	ΔY, ft	ΔZ, ft				X _{c.m.}	X ₁	X ₃	Y _{c.m.}	Y ₁	Y ₂	Y ₃	Z _{c.m.}	Z ₁	Z ₂	Z ₃		
	<table><tr><td>1</td><td>1</td></tr></table>	1	1	4	2	2	16	6.7	216	10.6	16.8	23.5	16.8	23	42	48	17	23	42	48
	1	1																		
	<table><tr><td>1</td><td>2</td></tr></table>	1	2	4	2	2	16	9.88	318	15	23.7	32.4	23	33	49	57	23	33	49	57
	1	2																		
<table><tr><td>2</td><td>2</td></tr></table>	2	2	4	2	2	16	13	470	19	30.2	41.4	31	42	76	87	31	42	76	87	
2	2																			
<table><tr><td>3</td><td>4</td></tr></table>	3	4	7	3.5	3.5	86	14.4	463	51.5	90	128	84	129	185	223	84	129	185	223	
3	4																			
	<table><tr><td>1</td><td>1</td></tr></table>	1	1	4	4	2	32	19.7	636	47.8	117	135	46	66	97	114	64	84	115	132
	1	1																		
	<table><tr><td>2</td><td>2</td></tr></table>	2	2																	
	2	2																		
<table><tr><td>3</td><td>1</td></tr></table>	3	1	4.5	4	2.5	41	23.5	756	33.8	128	151	63	108	221	245	69	171	227	322	
3	1																			
<table><tr><td>3</td><td>2</td></tr></table>	3	2	4.5	4	2.5	41	29.8	960	48	167	197	82	130	226	256	92	233	260	369	
3	2																			

TABLE II. - PACKAGES CONSTRUCTED WITH BASIC PACKAGES AS BUILDING BLOCKS - Continued

(a) SI Units - Concluded

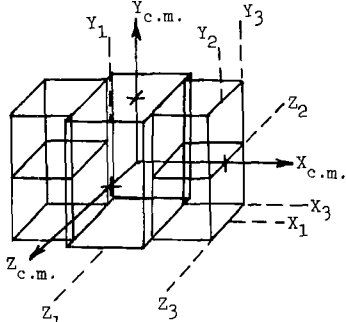
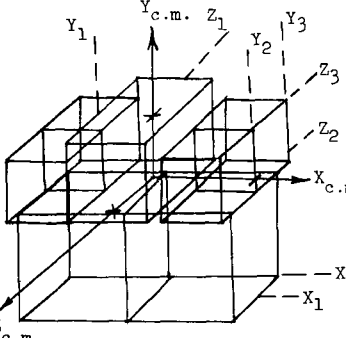
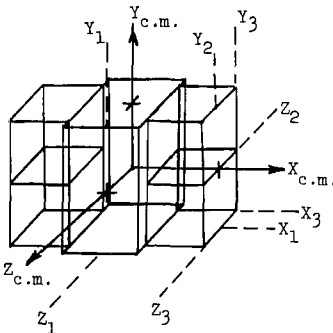
Sketch of package	Basic packages used and position	Approximate dimensions			Approximate volume, V, m ³	Mass, m, kg	Earth weight, N	Moment of inertia, I, kg-m ² , about -																
		ΔX, m	ΔY, m	ΔZ, m				X _{c.m.}	X ₁	X ₃	Y _{c.m.}	Y ₁	Y ₂	Y ₃	Z _{c.m.}	Z ₁	Z ₂	Z ₃						
	<table border="1"><tr><td>1</td><td>3</td><td>2</td></tr><tr><td>1</td><td></td><td>2</td></tr></table>	1	3	2	1		2	2.0	1.2	0.76	1.61	533	4964	88	285	334	193	270	595	645	216	413	632	844
1	3	2																						
1		2																						
	<table border="1"><tr><td>1</td><td>5</td><td>2</td></tr><tr><td>4</td><td></td><td>3</td></tr></table>	1	5	2	4		3	2.1	1.8	1.2	4.05	744	7295	290	1228	1512	386	660	1228	1504	497	821	1341	1392
1	5	2																						
4		3																						

TABLE II. - PACKAGES CONSTRUCTED WITH BASIC PACKAGES AS BUILDING BLOCKS - Concluded

(b) U.S. Customary Units - Concluded

Sketch of packages	Basic packages used and position	Approximate dimensions			Approximate volume, V, ft ³	Mass, m, slugs	Earth weight, lbf	Moment of inertia, I, slug-ft ² , about -																
		ΔX , ft	ΔY , ft	ΔZ , ft				X _{c.m.}	X ₁	X ₃	Y _{c.m.}	Y ₁	Y ₂	Y ₃	Z _{c.m.}	Z ₁	Z ₂	Z ₃						
	<table border="1"><tr><td>1</td><td>3</td><td>2</td></tr><tr><td>1</td><td></td><td>2</td></tr></table>	1	3	2	1		2	6.5	4	2.5	57	36.5	1116	65	211	247.5	143	200	441	478	160	306	468	625
1	3	2																						
1		2																						

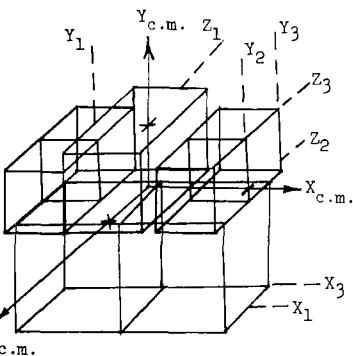
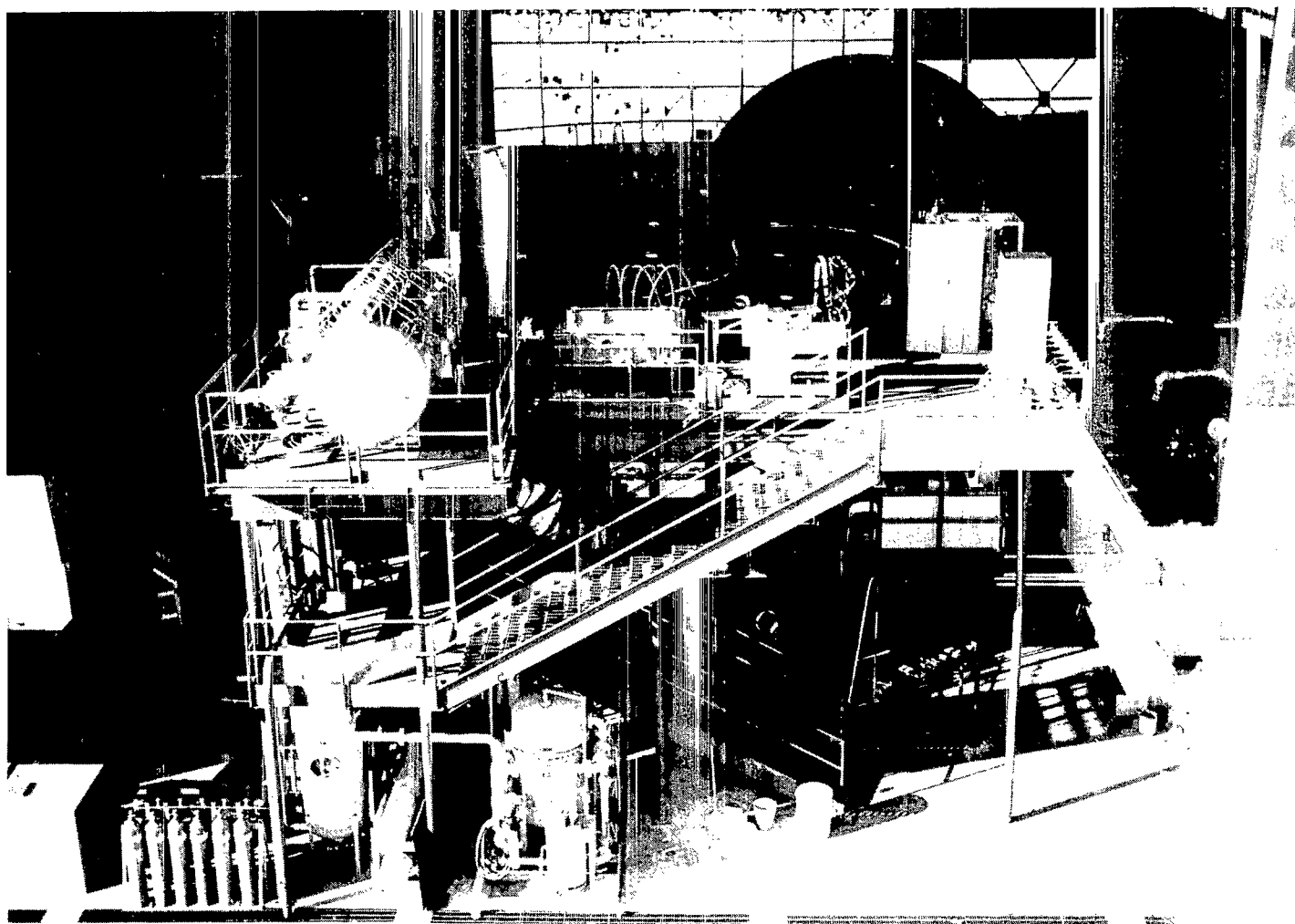
	<table border="1"><tr><td>1</td><td>5</td><td>2</td></tr><tr><td>4</td><td>3</td><td></td></tr></table>	1	5	2	4	3		7	6	4	143	51	1640	215	910	1120	285	489	910	1114	368	608	993	1031
1	5	2																						
4	3																							

TABLE III. - SUBJECT RATING SCALE

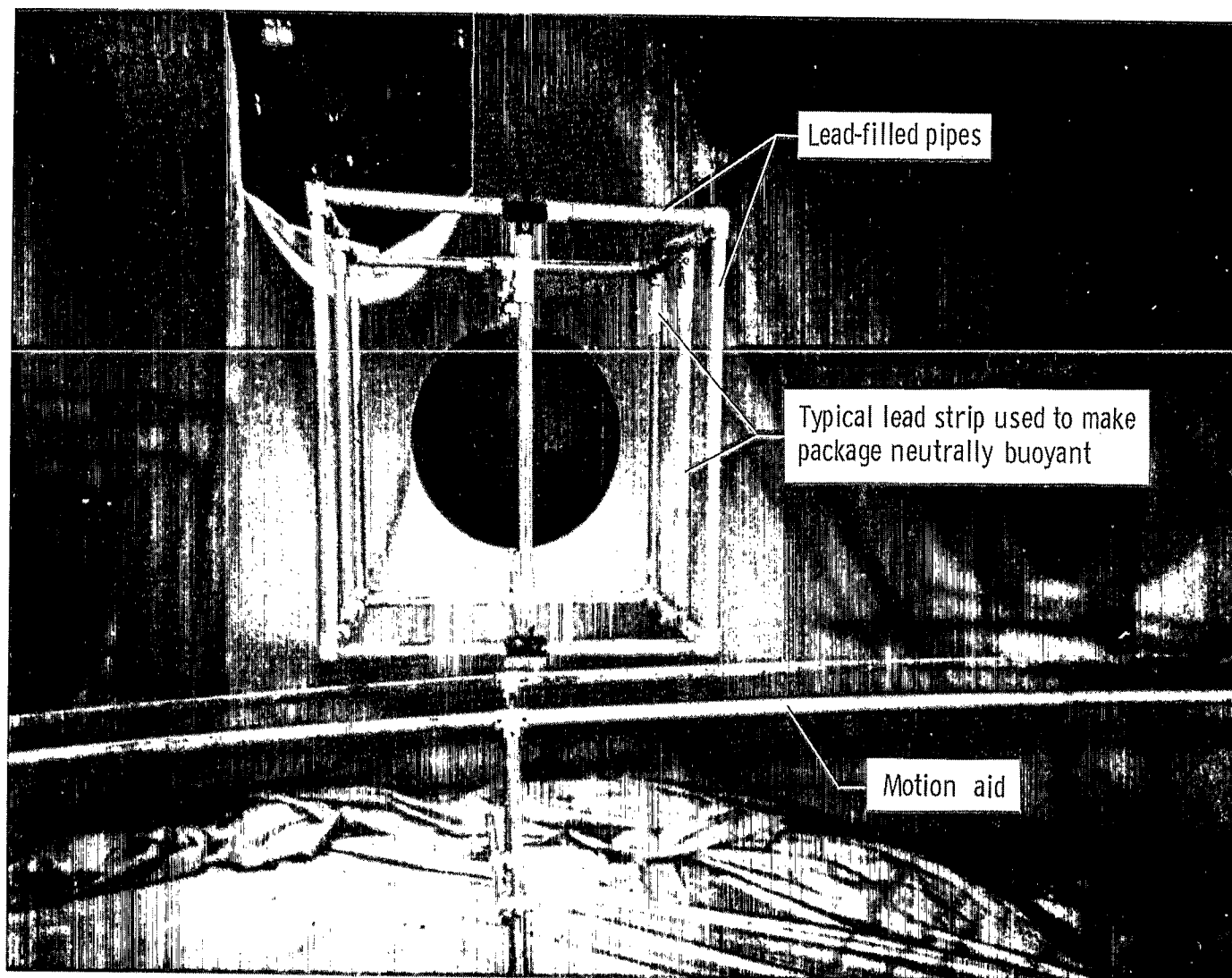
Ability to Perform Task	Package Characteristics	Demands on the Subject for Selected Task	Subject Rating
Satisfactory	Excellent - Highly desirable	Subject compensation* not a factor for desired performance	1
	Good - Negligible deficiencies	Subject compensation not a factor for desired performance	2
	Fair - Some mildly unpleasant deficiencies	Minimal subject compensation required for desired performance	3
Moderately satisfactory	Minor but annoying deficiencies	Desired performance required moderate subject compensation	4
	Moderately objectionable deficiencies	Adequate performance requires considerable subject compensation	5
	Very objectionable but tolerable deficiencies	Adequate performance requires extensive subject compensation	6
Unsatisfactory	Major deficiencies	Adequate performance not attainable with maximum tolerable subject compensation Controllability not in question	7
	Major deficiencies	Considerable subject compensation is required for control	8
	Major deficiencies	Intense subject compensation is required to retain control	9
	Major deficiencies	Control will be lost during some portion of required operation	10

*Compensation is defined as concentration and/or physical strength.



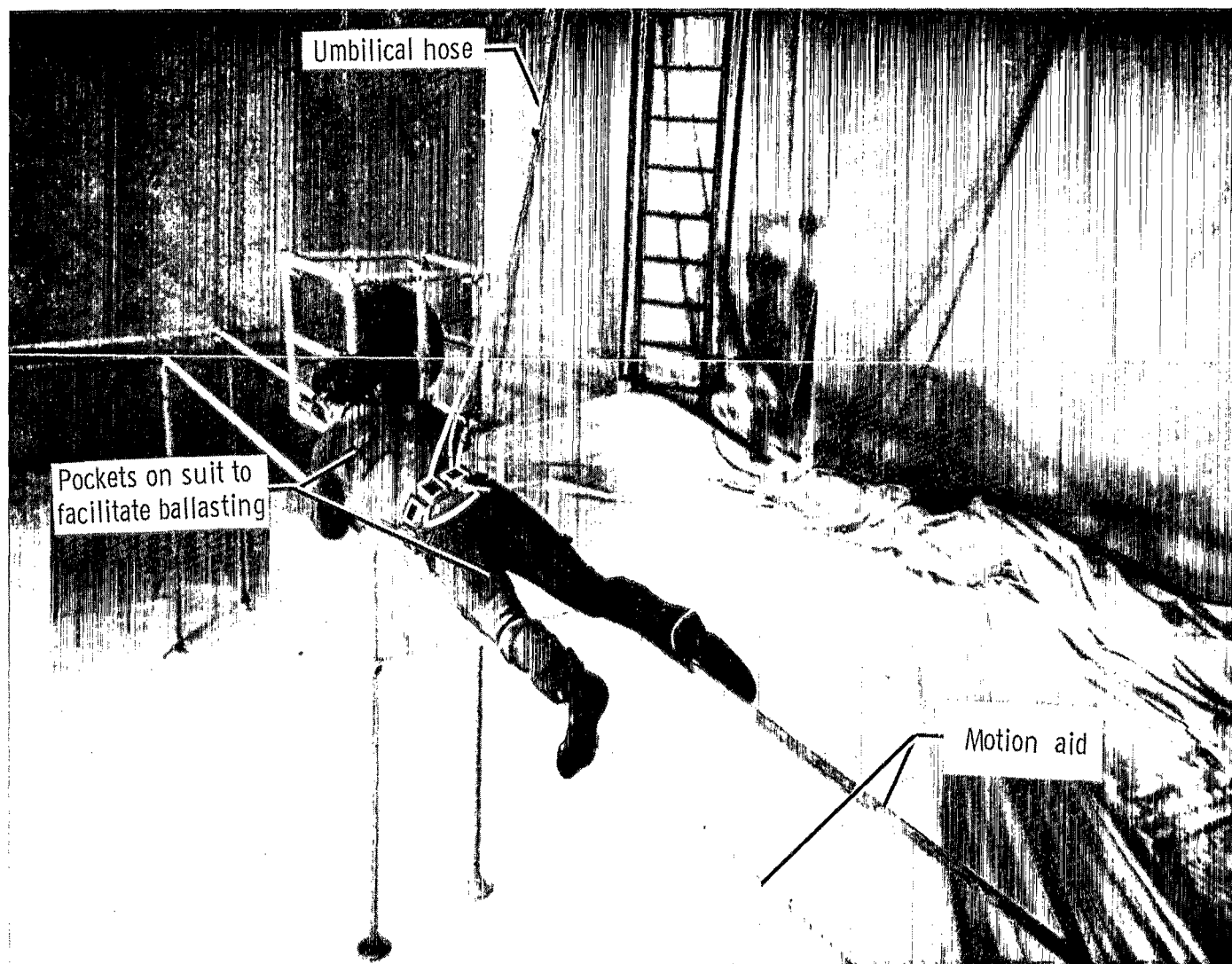
L-71-3034

Figure 1.- Photograph of water immersion simulator at the Langley Research Center.



L-72-193

Figure 2.- Typical package used for testing purposes (package 4, table I).



L-72-194

Figure 3.- View of subject transferring the reference package along the motion aid.

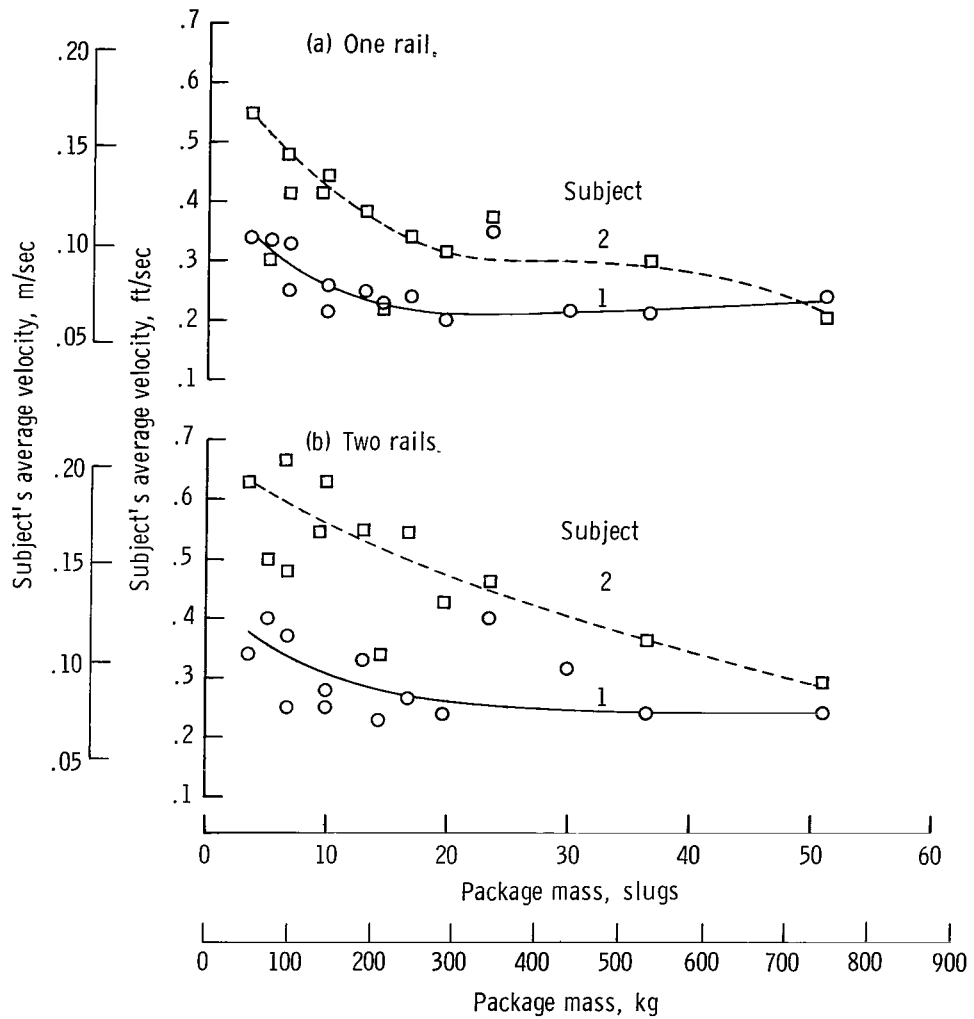


Figure 4.- Subjects' average velocity as a function of package mass.

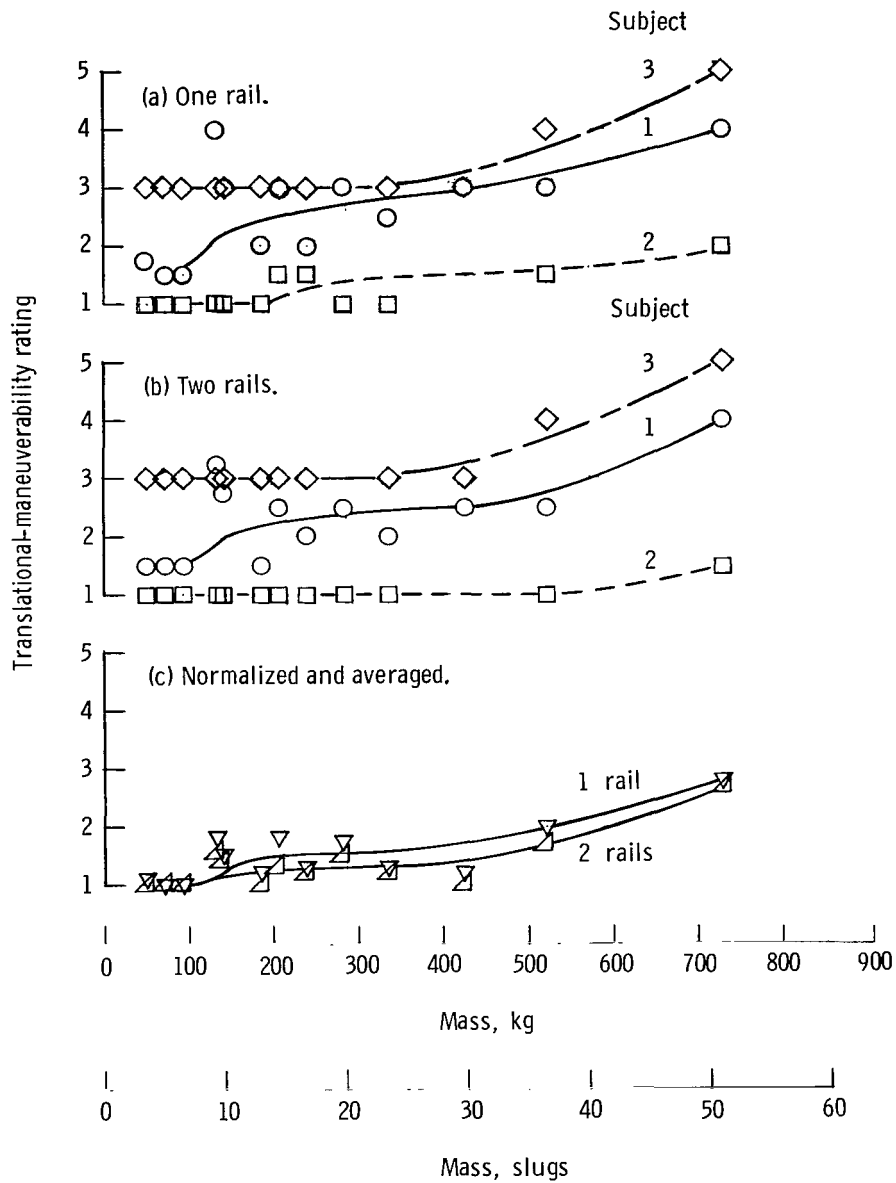


Figure 5.- Subjects' translational-maneuverability ratings as a function of package mass.

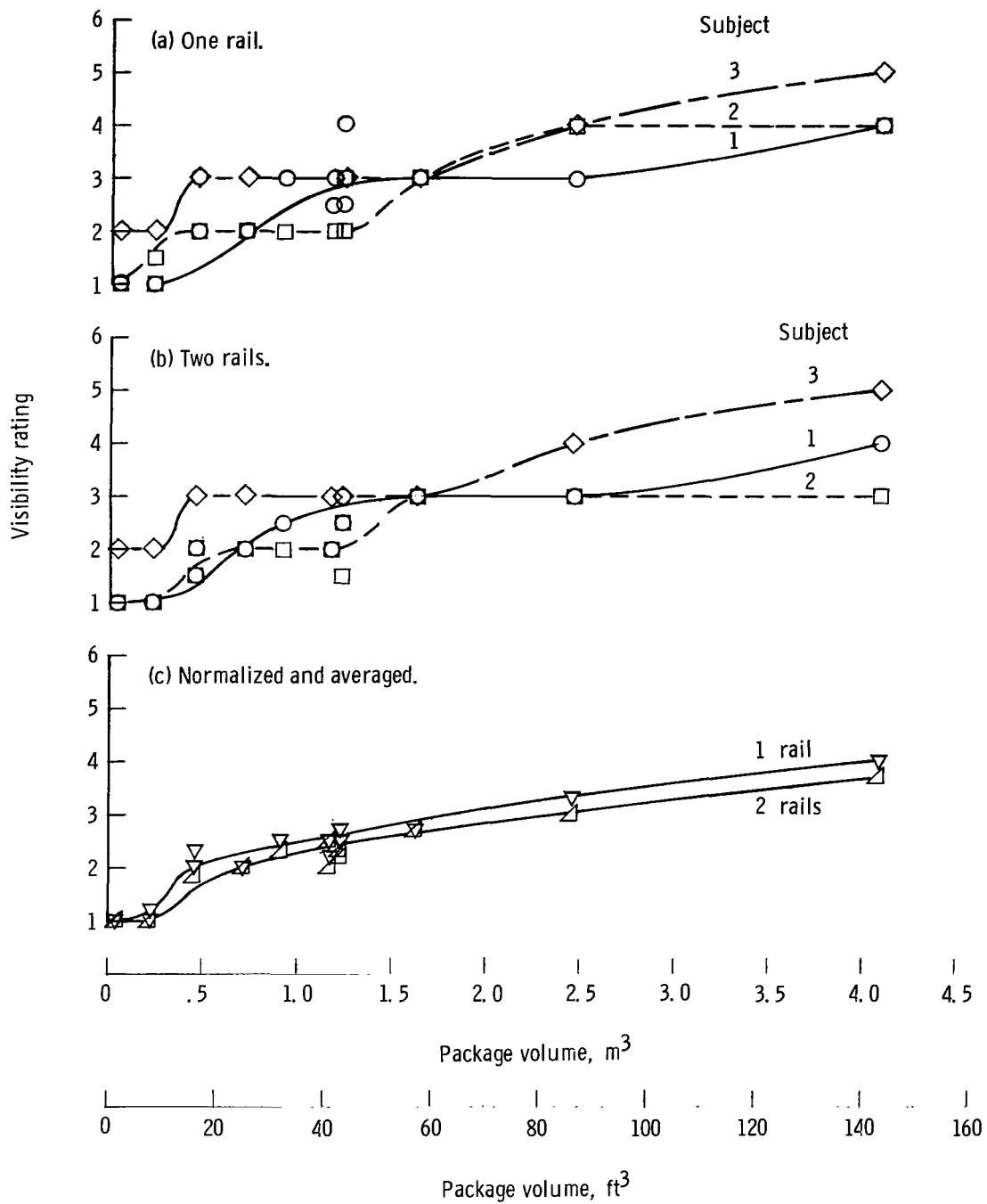


Figure 6.- Subjects' visibility ratings as a function of package volume.

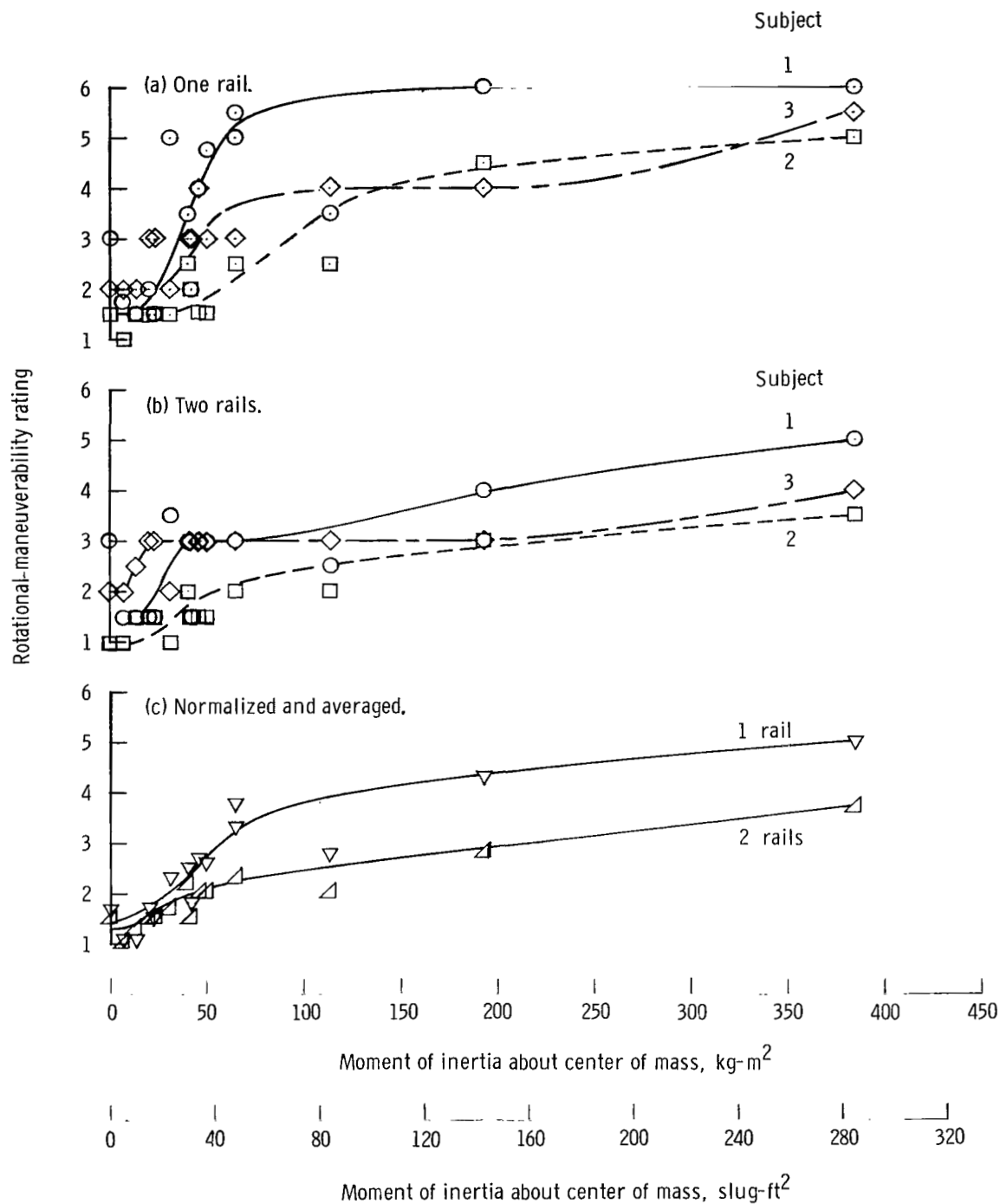


Figure 7.- Subjects' rotational-maneuverability ratings as a function of package moment of inertia about its center of mass.

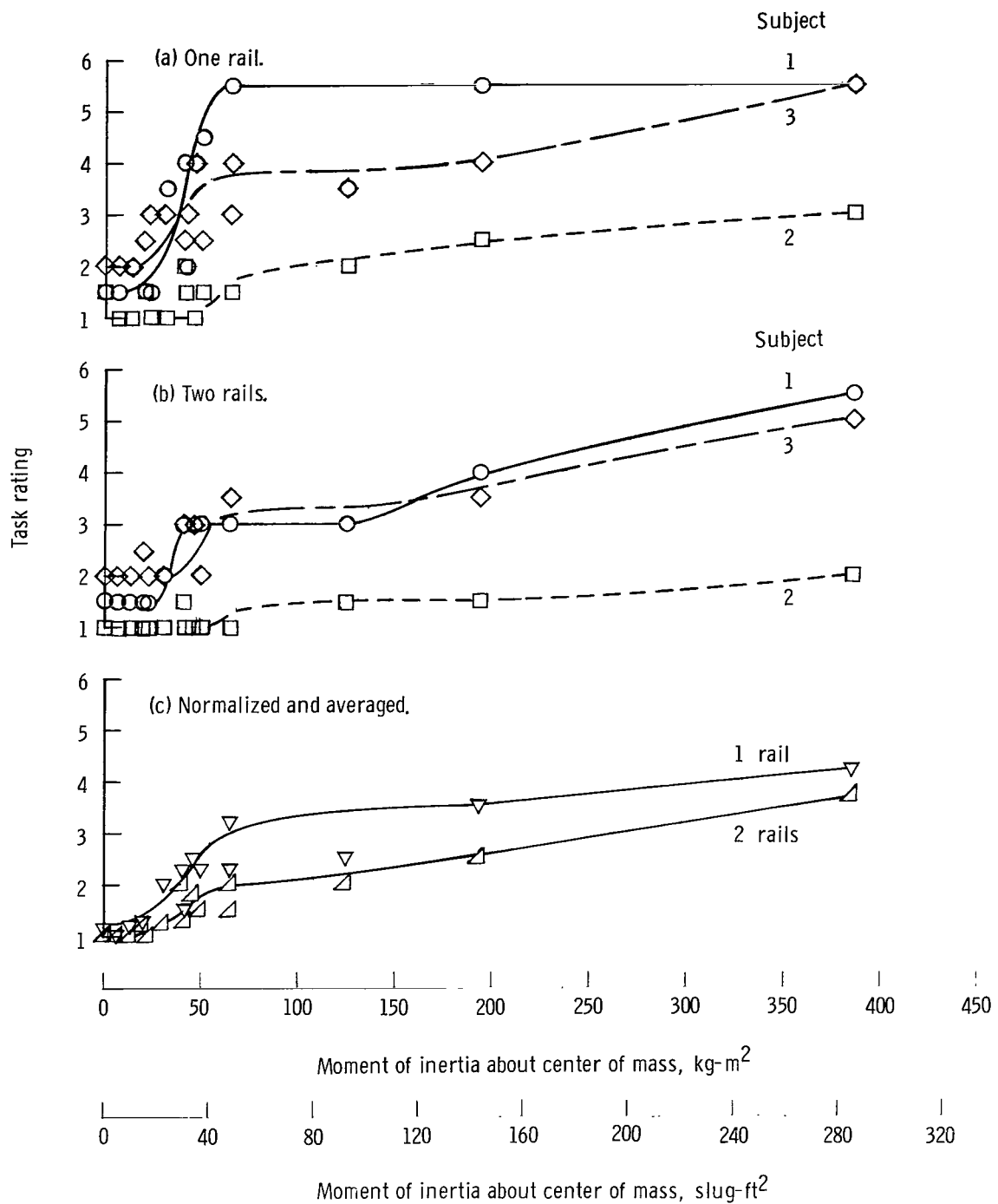
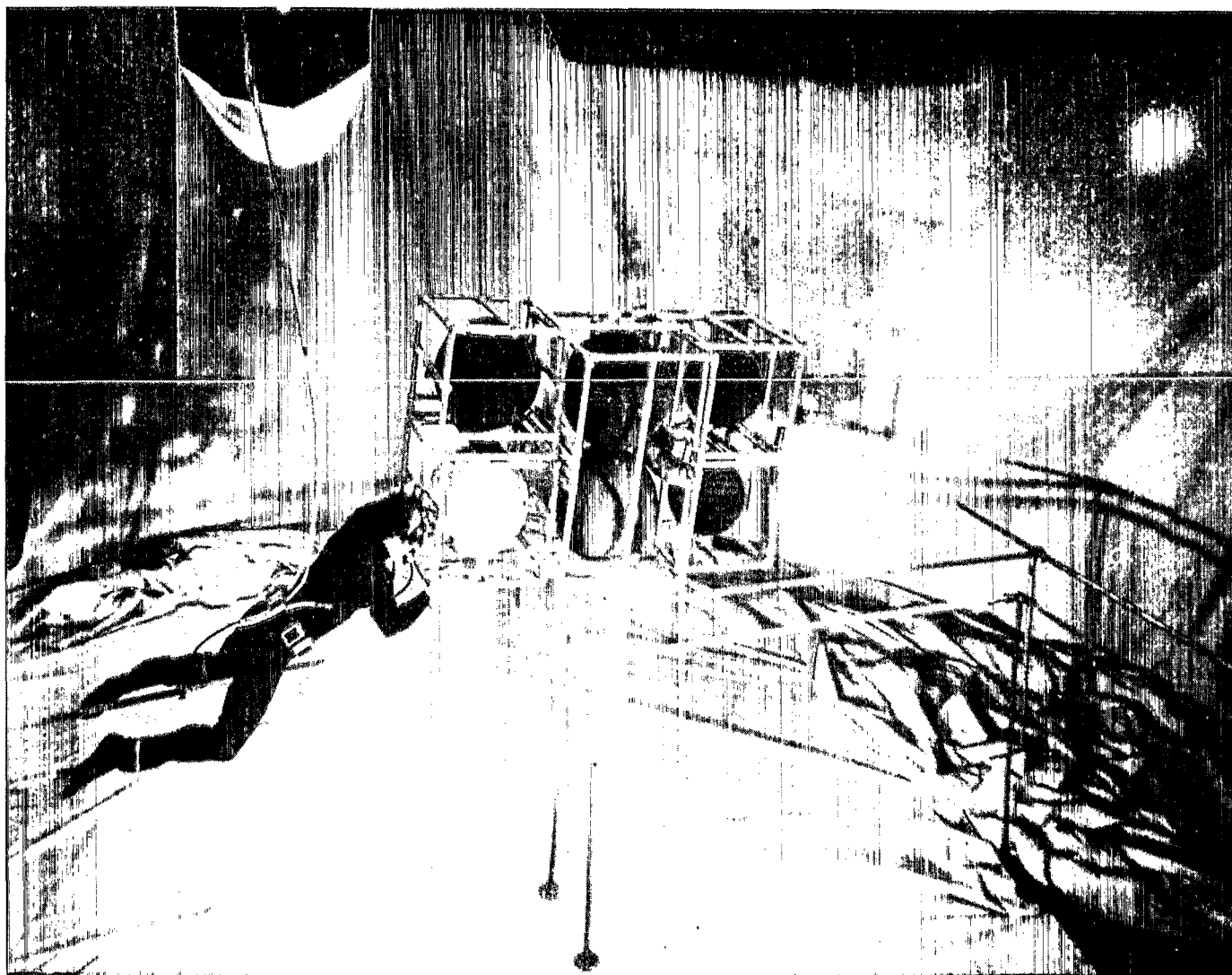
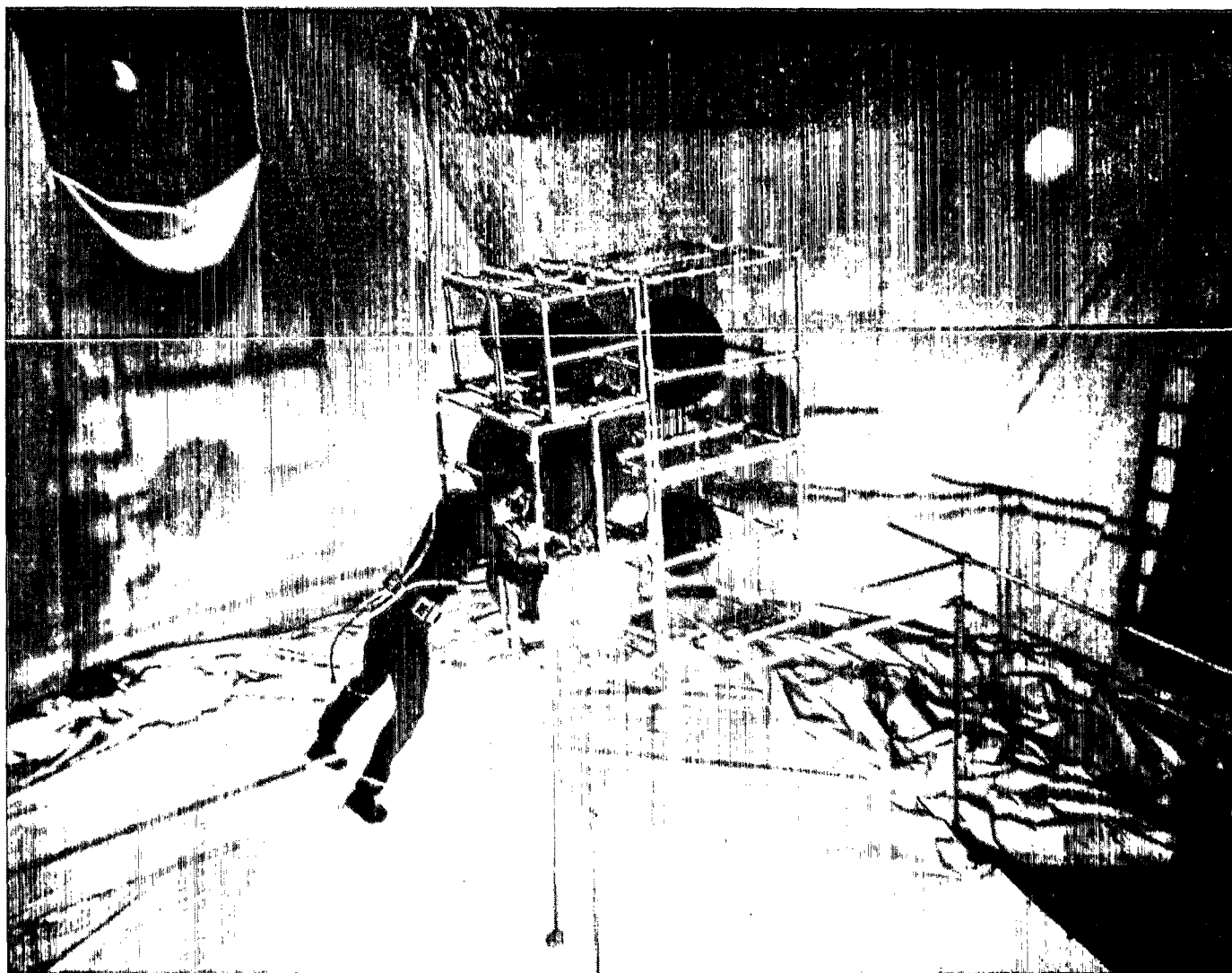


Figure 8.- Subjects' task-effort ratings as a function of package moment of inertia about its center of mass.



L-72-195

Figure 9.- Test subject in a crawl position transferring a 533-kg (36.5-slug) package.



L-72-196

Figure 10.- Test subject in a walking position transferring a 744-kg (51-slug) package.

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